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CVD Diamond Detector Stability Issues for Operation at the National Ignition Facility

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Abstract: *Synthetic diamond crystals produced by the Chemical Vapor Deposition (CVD) technique can serve as fast, radiation hard, neutron sensors for the National Ignition Facility (NIF). Here we explore the stability issues, such as charge trapping and high-flux saturation, that will be relevant to operation at the NIF.*

I. Introduction

We have been studying the application of synthetic diamond neutron sensors to the field of Inertial Confinement Fusion (ICF) neutron detection [1][2]. Unlike standard single particle counting, the neutrons in ICF appear at the detector in a single, strong, pulse. By recording the temporal shape of the neutron pulse, it is possible to determine the neutron energy spectrum using time-of-flight. For example, for a detector a distance d from the target chamber center (TCC), the recorded temporal data can be plotted as:

$$[t, \Delta S/\Delta t], \tag{1}$$

where t is the time-of-flight time to the detector ($=t_s-t_0$, where t_s is the sampled time and t_0 is the implosion time), ΔS is the sampled signal, and Δt is the sampled time width. The neutron energy spectrum can then be plotted as:

$$[E, (\Delta S/\Delta t)*(t^3/md^2)/\varepsilon(E)], \tag{2}$$

where E is the neutron energy ($=0.5*m*d^2/t^2$), m is the neutron mass, and $\varepsilon(E)$ is the relative neutron efficiency of the detector as a function of energy.

Using neutron spectroscopy to look for secondary or downscattered neutrons has been discussed [1,2]. Another application is to look for the Doppler broadening of the neutron peaks which is related to ion temperature. At the NIF, ion temperatures between 5 keV (a dud) to 50 keV (full ignition) are expected. For a detector just inside the chamber wall at 5 meters, this corresponds to DT temporal widths between 1.4 and 4.3 ns. A temporal resolution of 1 ns or better is thus required. Using DD neutrons at OMEGA, we have demonstrated this requirement (Figure 1). Figure 2 shows the Doppler broadening on the peak width that can be expected for 7 keV DD implosions. Figure 3 shows some of the DD temperature data that has been acquired.

One of the important issues we now face is stability of detector operation in the face of charge trapping and high flux saturation.

II. Charge trapping and saturation

Figure 4 shows the performance of CVD diamond for three separate DT shot days. Some irradiation also took place between these days, but data was not acquired, or is not available (with the exception of the data shown in Figure 5). The change in sensitivity and FWHM is quite noticeable. Figure 5 shows data from a series of high yield DT shots. The fall off in sensitivity with high flux is due to the impedance of the external circuit, and follows the theoretical expectation.

III. Proposed Solutions

Experimental work from a research group at CERN [4] suggests that radiation pumping (controlled irradiation with a strong radioisotope) can fill deep traps, and lead to stable performance – at least in single particle counting mode. However, the application of radiation pumping to current mode neutron detection has not yet been explored. With regards to saturation effects, they can be avoided by selecting crystals with a drift distance less than those shown in Figure 6. This can be accomplished by deliberate radiation damage, or by using very thin detectors.

IV. Future directions

One interesting future direction would be to use single crystal CVD diamond [5] instead of polycrystalline diamond. This grade of diamond does not trap charges (see Figure 7), and thus stability issues could possibly be avoided. High speed can be maintained by using very thin thickness values (<250 microns). This would have the additional advantage of avoiding high flux saturation effects (see Figure 6 with the drift distance equal to the thickness). Figure 8 shows the neutron response of single crystal CVD diamond. Besides using diamond, other options for trapping-free devices are silicon or GaAs. However, these devices would have inferior speed (because the saturation velocities are lower and the dielectric constants are higher) and more problems with radiation damage (damage thresholds are much lower in Si and Gas).

V. Conclusions

CVD diamond has the potential to serve as a fast, radiation hard, neutron sensor for the National Ignition Facility. However, issues regarding stable performance over the necessary yield range must first be addressed. We have outlined a plan here to accomplish this.

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References

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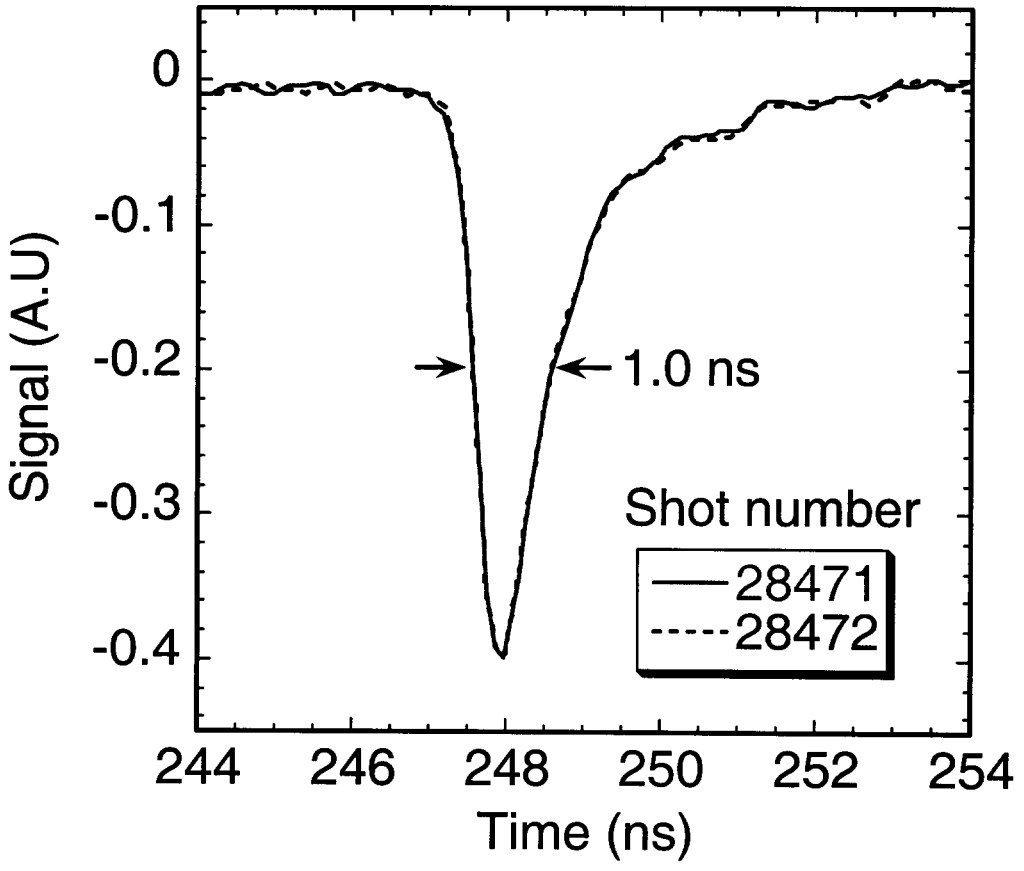

Figure 1: Response times of a polycrystalline diamond to DD neutrons from an OMEGA implosion. The detector was at 8cm from TCC and the total neutron yield was 1.6×10^{11} for both shots. Doppler broadening is negligible at this distance.

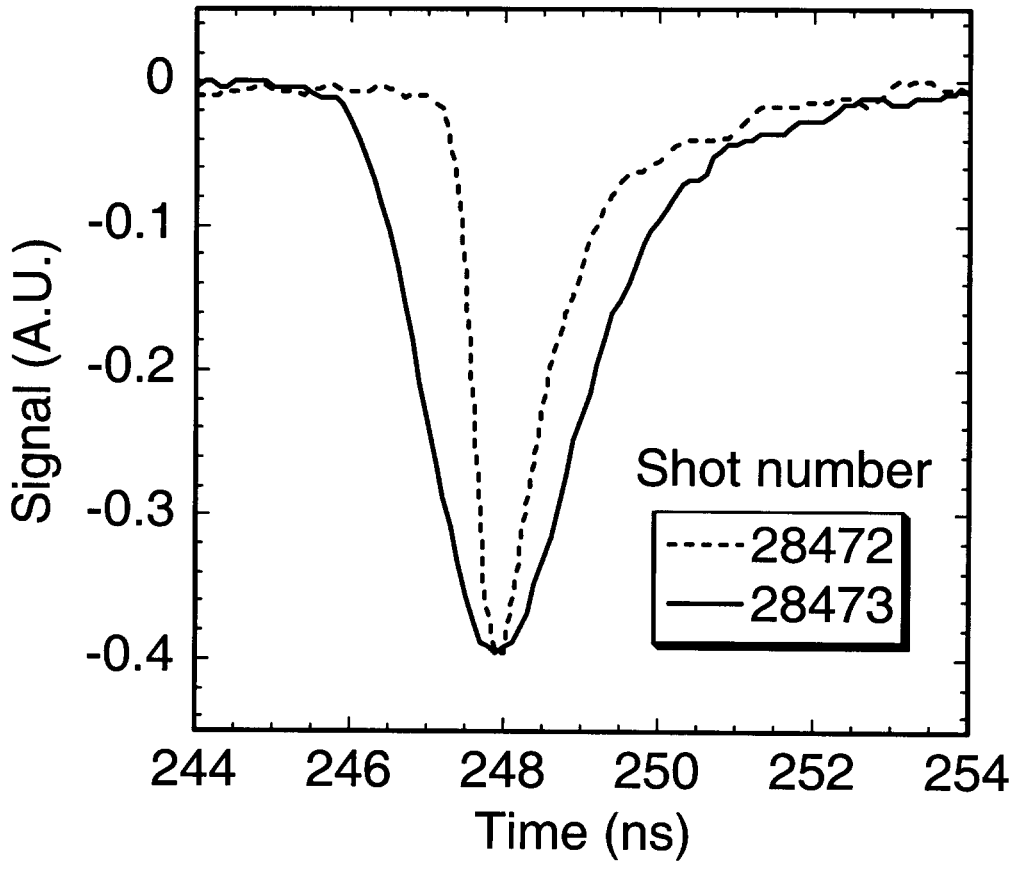

Figure 2: Doppler broadening the primary neutron peak in polycrystalline CVD diamond due to a fuel ion temperature of 7.2 keV for an OMEGA DD implosion. The detector is at 80 cm from TCC, with a total neutron yield of 2.6×10^{11}.

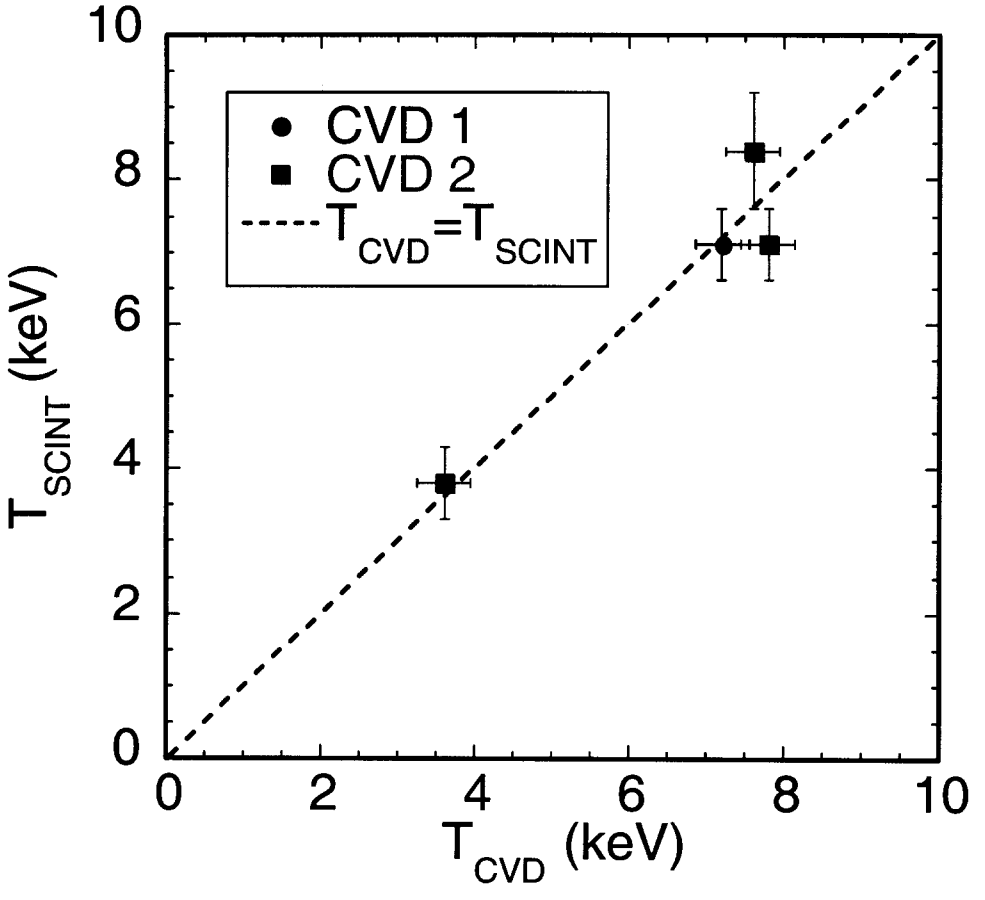

Figure 3: The ion temperature for DD shots at OMEGA as acquired with two polycrystalline CVD diamond detectors (CVD1, CVD2) and a current mode scintillator [3].

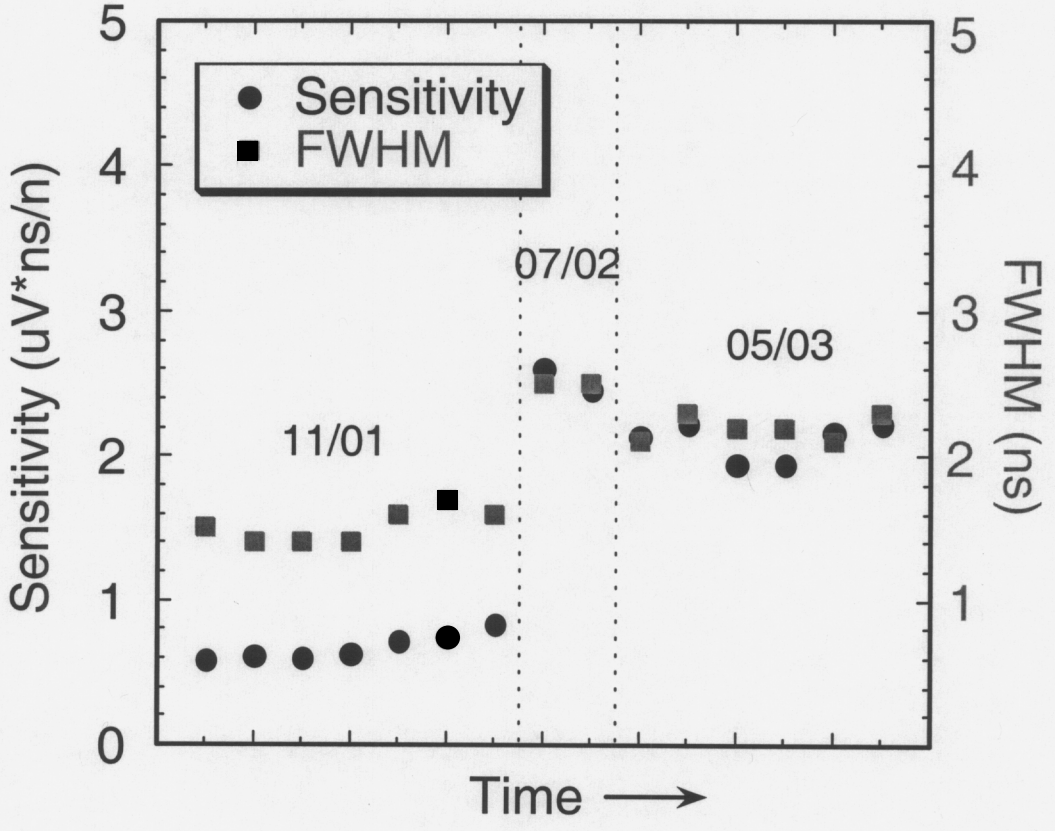

Figure 4: Variation in sensitivity and temporal response for polycrystalline CVD diamond as a function of time (the date of the shot days are shown above the data).

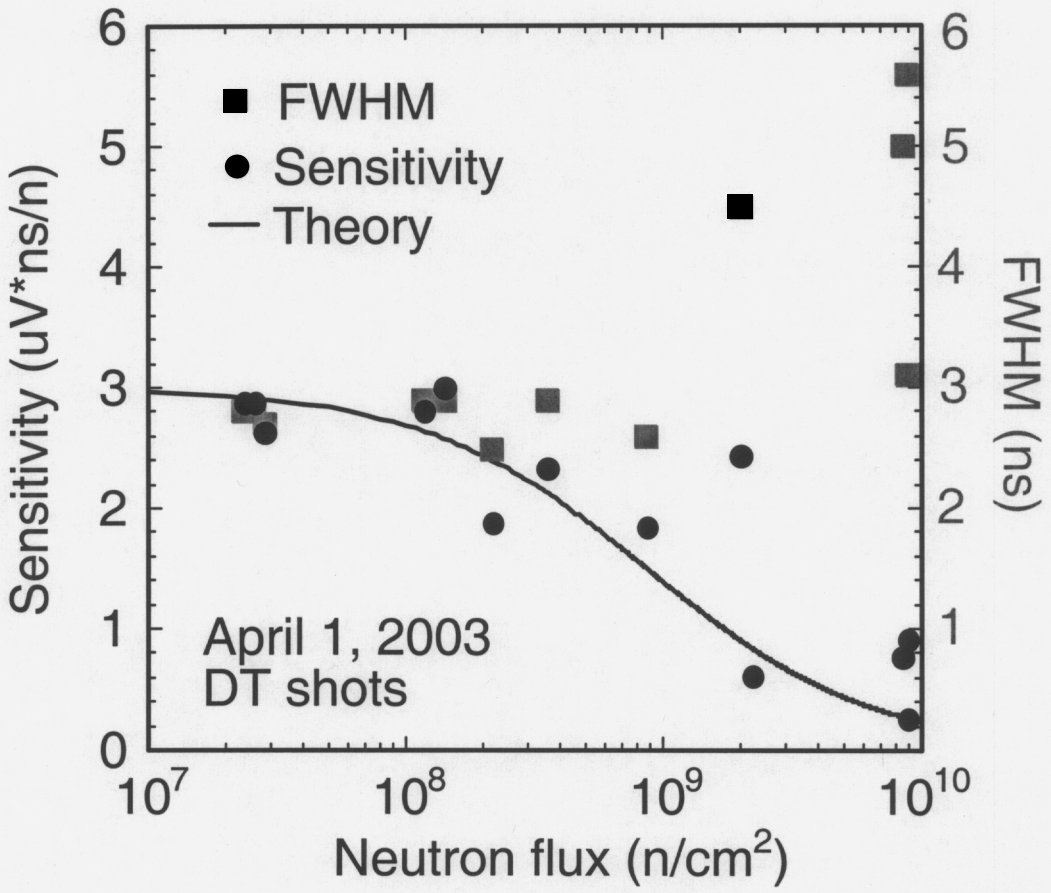

Figure 5: High flux saturation in polycrystalline CVD diamond.

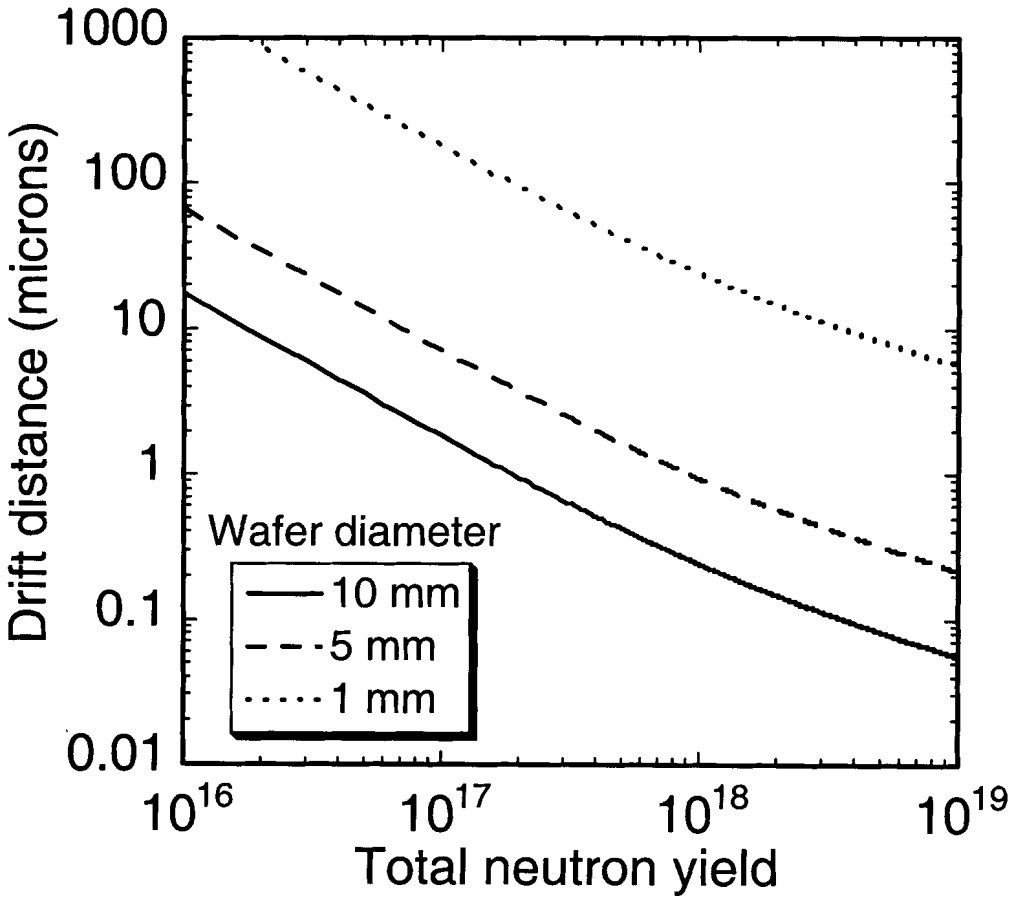

Figure 6: For polycrystalline CVD diamond, this plot refers to the maximum charge collection distance that can be used and still avoid high flux saturation at 5 meters from TCC. For single crystal diamond, the y-axis refers to detector thickness.

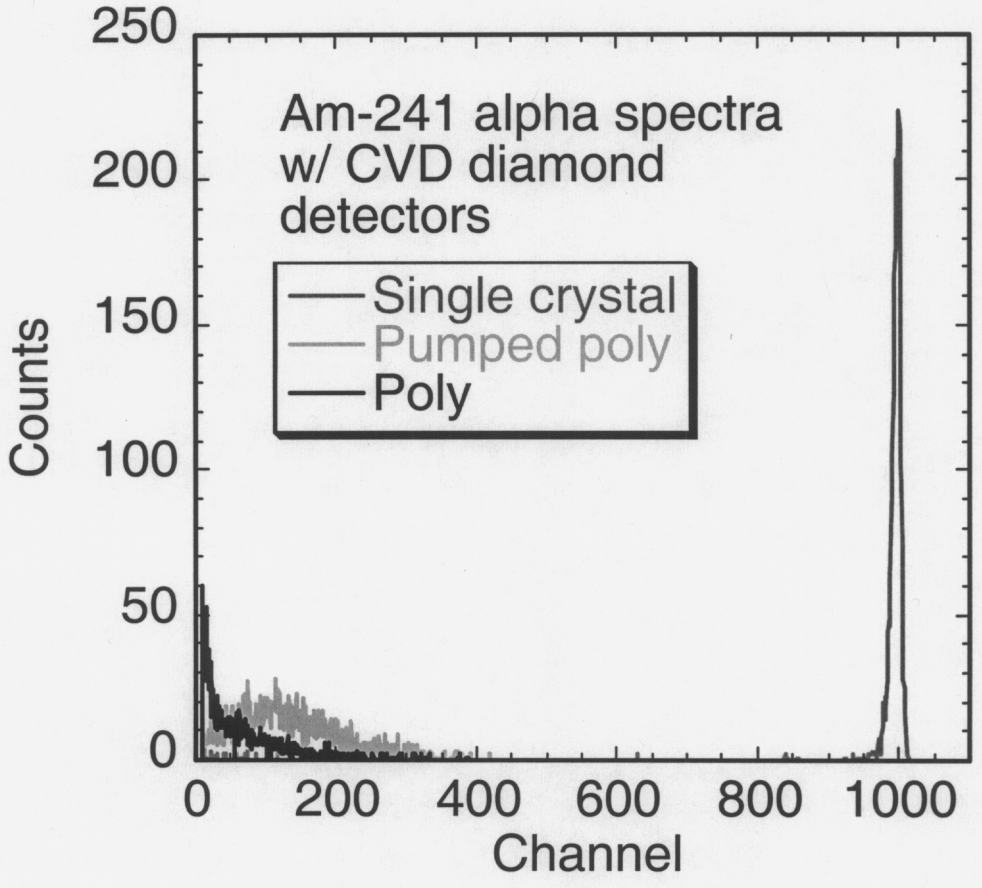

Figure 7: Am-241 spectra for CVD diamond detectors.

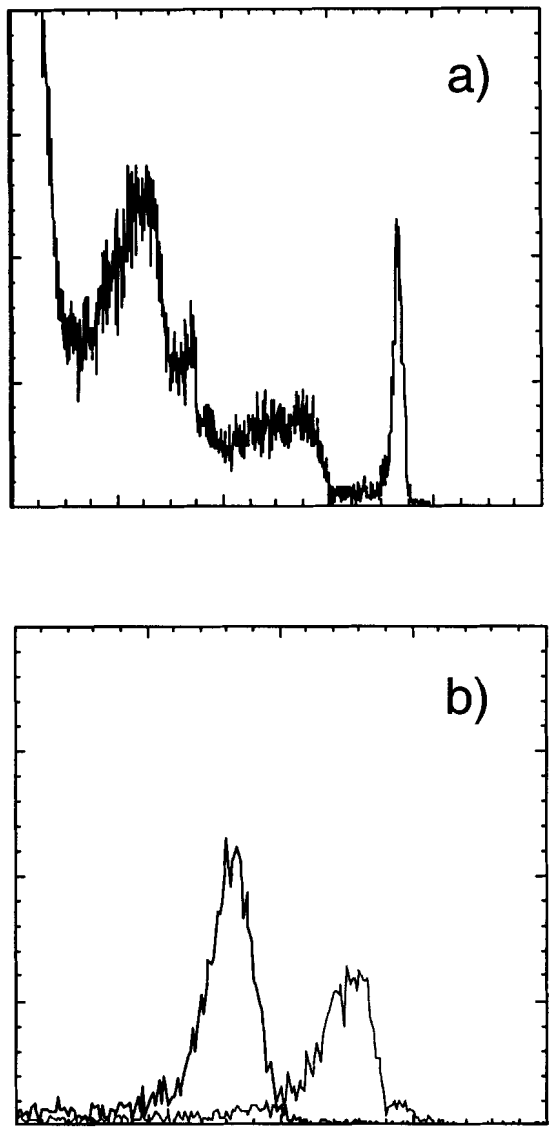

Figure 8: Pulse height spectra for single crystal CVD diamond detector. Data acquired in single particle counting mode at D+T neutron generator.